National Exams December 2010

07-Elec-A5, Electronics

3 hours duration

Notes:

1. If any doubt exists as to the interpretation of any question, the candidate is urged to submit, within their answer, a clear statement of any assumptions made.

2. This is a CLOSED BOOK EXAM. A Casio or Sharp approved calculator is permitted.

3. FIVE (5) questions constitute a complete exam paper. The first five questions as they appear in the answer book will be marked.

4. All questions are worth 20 marks each.

5. Please start each question on a new page and clearly identify the question number and part number, e.g. Q4(a).

6. In schematics, ground and chassis may be assumed to be common, unless specifically stated otherwise.

7. Unless otherwise specified, assume that Op-Amps are ideal and that supply voltages are ±15V.

8. Some questions require an answer in essay format. Clarity and organization of the answer are important. Provide block diagrams and circuit schematics whenever necessary.
QUESTION (1) a) Derive an expression for the output $v_{OUT}$ as a function of $R_1$, $R_2$, $R_3$, $R_4$, $v_1$, and $v_2$ in the following op amp circuit.  

b) If $R_1$ is comprised of a fixed resistor, $R_{1a}$ in series with a variable resistor, $R_{1b}$, determine the value of $R_{1a}$, $R_{1b}$, and $R_2$ that can provide a gain that varies from 5 to 500. Assume that $R_4 = 2R_3$. 

\[
\begin{array}{c}
\text{v}_1 \rightarrow A_1 \rightarrow R_2 \rightarrow A_2 \rightarrow R_2 \rightarrow A_3 \rightarrow R_4 \rightarrow v_{OUT} \\
\uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \\
R_1 \rightarrow R_{1a} \rightarrow R_{1b}
\end{array}
\]

QUESTION (2)  
i) For this full-wave rectifier circuit, assume that the diodes are ideal with zero forward voltage drop and that the time constant $RC = 100$ ms. For a 1 kHz triangular input waveform with a peak amplitude of 10V, and using the assumption that $RC >> T$,

a) Sketch accurately in your answer book the output voltage waveform, $v_o$.  

b) What is the peak voltage, $V_p$ and the ripple voltage $V_r$ that would appear at the output?  

c) What is the average output voltage at $v_o$?  

d) Estimate the time interval, $t_{on}$ during which the diodes conduct during each period.
QUESTION (3)

For this circuit,

\[ V_{TH} = 1 \text{ V} \text{ (for both transistors } M_1 \text{ and } M_2) \]

\[ K = 2 \text{ mA/V}^2 \quad \lambda = 0.01 \text{ V}^{-1} \]

\[ V_{CC} = |V_{EE}| = 10 \text{ V} \quad V_G = 1 \text{ V} \]

\[ R_D = 3 \text{ k}\Omega \quad C_1 = C_2 = \infty \]

\[ I_{bias} = 2 \text{ mA} \]

(a) Determine the gain \( v_o/v_i \). (10 points)

(b) Determine the input and output resistance, \( R_{in} \) and \( R_o \). (5 points)

(c) What is maximum peak to peak input voltage that can be applied while still keeping \( M_1 \) operating in the saturation region? (5 points)

Useful formulae: for n-channel MOSFET

\[ i_{DS} = K \left[ 2(v_{GS} - V_{TH})v_{DS} - v_{DS}^2 \right] \quad \text{triode region} \]

\[ i_{DS} = K (v_{GS} - V_{TH})^2 \left( 1 + \lambda v_{DS} \right) \quad \text{saturation region} \]

QUESTION (4)

A real op amp is modeled by an ideal op amp, input bias current sources and an input offset voltage source.

Given \( V_{IO} = 10 \text{ mV} \), \( I_{b1} = I_{b2} = I_b = 100 \text{ nA} \)

\( R = 100 \text{ k}\Omega \)

(a) Derive an expression for \( v_{OUT} \) as a function of \( v_1 \) and \( v_2 \). (14 points)

(b) What is the value of the output voltage, \( v_{OUT} \) if both \( v_1 \) and \( v_2 \) are set to zero? (6 points)
QUESTION (5)

Assume that the BJT has the following characteristics:
\[ \beta = 100 \]
\[ V_{BE(on)} = 0.7 \text{V} \]
\[ V_{CE(sat)} = 0.3 \text{V} \]
\[ V_A = \infty \]

Given:
\[ V_{CC} = 10 \text{ V} \]
\[ R_L = 10 \text{ k} \Omega \]
\[ R_E = 200 \text{ } \Omega \]

a) Design this common emitter amplifier circuit to have the following specification:
   - DC bias current, \( I_E = 1 \text{mA} \)
   - A mid-band voltage gain \( v_{out}/v_s = -100 \text{ V/V} \)
   - Provide values for \( R_1, R_2, \) and \( R_C \). (15 points)

b) What is the equivalent output resistance, \( R_O \)? (2 points)

c) What is the maximum undistorted peak to peak output voltage swing at the output? (3 points)

QUESTION (6) Solve for the currents \( I_1, I_2, \) and \( I_3 \) in the following diode circuit. (20 points)

Given:
All diodes are ideal with 0.6V forward drop
\[ R_1 = R_2 = R_3 = 10 \text{ k} \Omega \]